Dynamics of strain-hardening and strain-softening capsules in strong extensional flows

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Introduction

In the present study we investigate the dynamics of initially spherical capsules (made from elastic membranes obeying the strain-hardening Skalak or the strain-softening neo-Hookean law) in strong planar extensional flows. Current understanding of capsule dynamics at high flow rates is rather limited since no analytical solutions exist (due to the inherit non-linearity associated with the membrane tensions) while the state of the art (low-order) three-dimensional computational methodologies are unable to find (and thus provide physical insight on) stable steady-state capsule shapes at high flow rates.

Results

Based on computational investigation via our interfacial spectral boundary element algorithm, our study suggest that no critical flow rate exists for both Skalak and neo-Hookean capsules at strong extensional flows. As the flow rate increases, both capsules reach flat elliptical steady-state configurations; the cross-section of the Skalak capsule preserves its elliptical shape while the neo-Hookean capsule becomes more and more lamellar. The curvature at the pointed edges of these elongated shapes shows a very fast (exponential-like) increase with the flow rate. The large interfacial deformations are accompanied with the development of strong membrane tensions especially for the strain-hardening Skalak capsule; the computed increase of the membrane tensions with the flow rate can be used to predict rupture of a specific membrane (with known lytic tension) due to excessive tensions.

Conclusions

At large deformations, the analytical determination of membrane dynamics for nonlinear membrane laws is practically unattainable; thus, computational investigation is an attractive alternative. The large values of the edge curvature for both types of capsule along with the fact that the membrane tensions are complicated functions of the interfacial geometry, clearly indicate the need for a highly-accurate computational methodology (such as our interfacial spectral algorithm) for the accurate determination of membrane dynamics in strong flows.